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A RFI Me surement System for Field Si s

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A compact system has been developed for performing RFI measurements at remote sites. This system covers a 0.5- to 18-GHz frequency range. The system's sensitivity meets or exceeds the sensitivity of a ground terminal when the interfering signals arrive through its wide-angle sidelobes. This sensitivity is achieved with a commercial spectrum analyzer and a specially designed preamplifier system. In addition, a combination of passive bandpass filtering and tuned band-reject filtering preserves the system's linearity when operating in the presence of strong signals. Example measurements illustrate the operation of this RFI measurement system.

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I. INTRODUCTION

The RF environment surrounding a ground terminal can limit the terminal's operation by interfering with its receiver. These interfering signals may be in-band, i.e., within the receiver's operating bandwidth, or out-of band, i.e., outside of the receiver's operating bandwidth. In-band interfering signals require a variety of techniques be utilized to obtain satisfactory performance of the ground terminal. The level of the interference may be reduced by a combination of techniques including (1) lowering the antenna sidelobes through various design techniques, such as tunnels surrounding the aperture, (2) reducing leakage in waveguide components, (3) obstructing the interference with RF fences, (4) using adaptive interference cancellation techniques, and (5) using additional modulation processing gain such as spread-spectrum modulation and/or error correction coding. Out-of-band interference can be negated by increasing the dynamic range of the receiver or using RF filtering techniques. Methods for reducing interference require some compromises in the total system noise performance which must be addressed for each specific application. The success of these design techniques for reducing in-band and out-of-band interference depend on the nature of the interference. Therefore, the interference spectrum and the power levels of the interference should be measured prior to implementing interference reduction techniques.

A simple, compact system has been developed to measure the RF environment at remote ground terminal sites and to determine the levels of interference a ground terminal will experience. Such a system must be sufficiently compact and rugged to permit shipment to the remote sites. It should cover a broad frequency range, and its sensitivity must meet or exceed the sensitivity of the system to be protected. Interfering signals cover a broad frequency range, and a 500-MHz to 18-GHz range was selected to cover a wide variety of microwave terminal needs. A general purpose spectrum analyzer forms the basis of this system by meeting the physical requirements and covering a broad frequency range. The required sensitivity of the measurement system was derived under the assumptions that the interference is received through the sidelobes of the antenna and that the maximum level of the susceptible sidelobes is bounded by an isotropic antenna gain level. Therefore, a simple frequency-independent antenna together with suitable preamplifiers to offset the noise figure of the spectrum analyzer can achieve the desired sensitivity goal. Some sites may have high-peak-power systems operating nearby; radar and other high-peak-power systems are widely used and are examples of the types of interfering systems that limit both the ground terminal and the measurement system. A combination of passive and tunable band-reject filters together with fixed attenuators reduce the high-level signals and preserve the linearity of the measurement system, so that signals in the remaining spectra can be observed with high sensitivity.

This measurement system fulfills two different measurement requirements. The first measurement requirement is to perform an initial survey prior to the installation of a ground terminal. Such a survey provides a basis for designing the receiver with regard to its dynamic range and filtering requirements. The second measurement requirement concerns existing ground terminal installations. Two different situations can arise. A measurement system of this type can be used for diagnostics, particularly when the existing terminal is not instrumented or is limited to making spectral measurements over a broad frequency range. A second situation arises when the frequency coverage of the operational system is to be extended, e.g., a popular option currently is to add a GPS receiver to a ground terminal to obtain time information.

The measured RF signals can be separated into three different categories, according to their peak power levels and their possible effect on the system. The first category is those signals that are sufficiently strong to damage the front-end electronics of the receiver. Modern low-noise preamplifiers use devices having extremely small dimensions. While low-noise performance is achieved, such devices have a limited ability to withstand exposure to high-peak-power levels. Burnout resulting from melting of the substrate occurs when these devices are subjected to high power levels. An example of the required incident field strengths for a 1-W damage level and an isotropic receiving antenna gain is presented in Figure 1 (Damage levels for typical low-noise devices may be found in Ref. 1). The values in this figure may be scaled to meet the device vulnerabilities of interest for the specific amplifier technology being used. Also shown in this figure is the field strength necessary to achieve the 10 mW/cm^2 power density typically used in radiation safety standards (Ref. 2). Signals in this category have very high peak power levels, which must be filtered to protect the terminal's receiver. These high signal levels are dangerous and should be avoided by personnel. The second category of signals have power levels necessary to saturate the system. When these signals are not filtered in the receiver's front end, the system performance is degraded by suppression of the desired signal and by generation of undesired intermodulation products. The third category is those signals that are insufficiently strong to saturate the system. When these signals are in-band, filtering techniques cannot be used since the desired signals will also be attenuated, and the precise degradation of such signals depends on the processing gain of the receiver and the desired waveform relative to the interference spectrum. Criteria must be developed to determine a tolerable SNIR (signal-to-noise-plus-interference ratio) for acceptable system operation; these criteria depend on system requirements and modulation characteristics, and establish the required interference suppression. The latter categories are a function not only of the sidelobe gain of the ground terminal antenna in the interference direction, but also the dynamic range of the receiver.

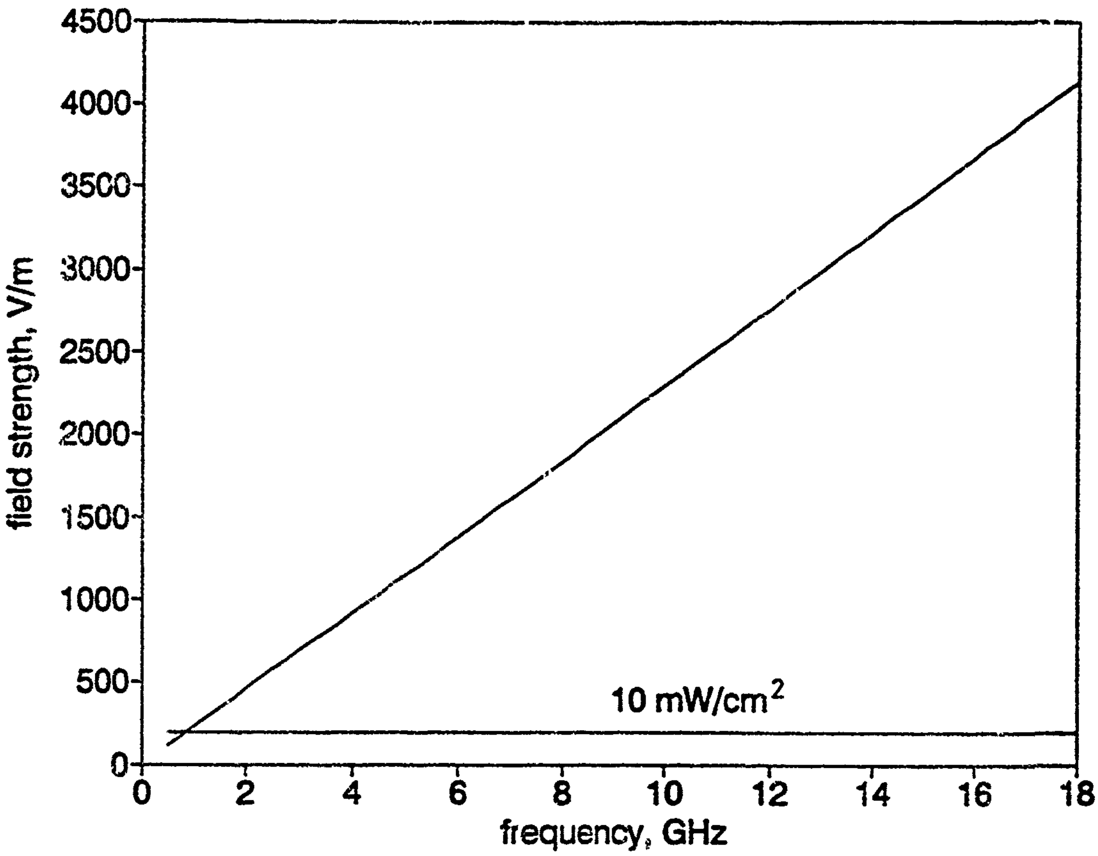


Figure 1. Incident field strengths that damage a system having a 1-W damage level and an isotropic antenna.

II. DESCRIPTION OF THE MEASUREMENT SYSTEM

The overall measurement system is shown in Figure 2. The system uses a log periodic antenna, shown mounted on the tripod. The shelf on the tripod holds the preamplifier system that was developed to allow the measurement system to meet the desired sensitivity goals. A Hewlett Packard 8563B spectrum analyzer was selected as the basis of the measurement system. This portable analyzer meets the MIL-T-28800C requirements for shipping and handling to remote sites; its size and modest weight (40 lbs) are also appropriate for field measurements. An instrumentation camera (Tektronics C-4) is a convenient way to record the measured data. The entire system is packed for shipment in the two storage boxes stacked beneath the spectrum analyzer in Figure 2; each box weighs approximately 75 pounds fully loaded. One shipping box is 24" x 22" x 19"; the other is 24" x 19" x 13".

The Watkins-Johnson AR7-19 log periodic antenna is designed for operation between 500 MHz and 18 GHz, the frequency range of interest. This antenna is relatively compact (14 in. at the base, 17 in. long, and 2 in. thick). The antenna is enclosed within a fiberglass radome that protects the antenna elements during shipment and measurement. The beamwidth is 70 deg in the E-plane and 110 deg in the H-plane; in operation, detents every 60 deg are used in the azimuth ring of the tripod and several elevation positions can be selected. The antenna can also be rotated 90 deg to measure the orthogonal polarization.

The preamplifier system was designed after consideration of two principal factors. The first factor is sensitivity; preamplification is required to offset the noise figure of the spectrum analyzer. The second factor is overall system linearity. Like the ground terminal for which these measurements are being made, the measurement system must operate in a linear region to avoid signal suppressions and undesired intermodulation products. A combination of gain partitioning in the preamplifiers, passive and tunable filters, and fixed attenuators is used to maintain linear operation under a wide variety of test conditions.

The preamplifiers in this system are divided into three operating bandwidths, 0.5 to 2 GHz, 2 to 6 GHz, and 6 to 18 GHz. The lower two bandwidths are partitioned into two separate amplifiers to provide flexibility in compromising the sensitivity for the sake of dynamic range. The overall preamplifier system is described in Figure 3. The measured gain and noise figure data, including both vendor data and measurements performed inhouse, are given in Figures 4, 5, and 6, and in Table 1 for each frequency bandwidth, respectively. The 1-dB compression point for each amplifier at its output terminal is given in Table 2.

The filters used in the preamplifier include both passive and tunable types. A total of four passive filters were selected. Two of the filters separate the lower frequency range into two segments (0.5 to 1 GHz and 1 to 2 GHz); these filters can isolate high-level TV signals from the upper portion of the band, or high-peak-power L-band signals from the lower portion of the band, depending on the measurement situation. The third filter covers the upper portion of the second frequency band with a bandpass characteristic between 3 and 6 GHz; this filter provides protection from high-level S-band signals. The fourth filter is a high pass design with a bandpass above 5 GHz for the highest frequency range; the purpose of this filter is to prevent high-level signals at lower frequencies from saturating the highest frequency amplifier. The bandpass characteristics and insertion loss of the passive filters are shown in Figures 7 and 8 respectively.

Two tunable band-reject YIG filters were also selected. The first filter covers a 0.5- to 2-GHz range and the second filter covers a 2- to 4-GHz range. These filters can reject a single isolated high-level

Figure 2. RFI measurement system. Shipping containers are underneath the spectrum analyzer.

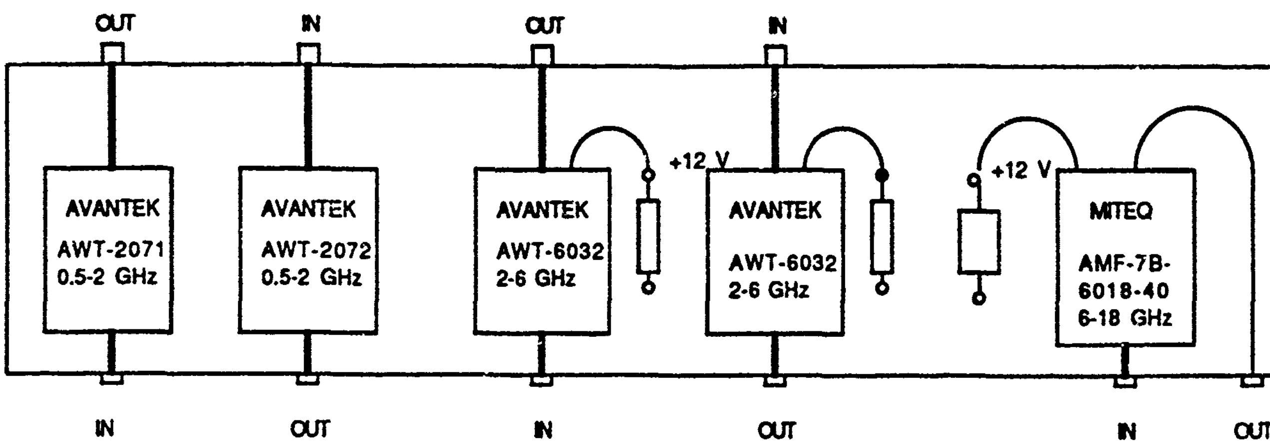


Figure 3. Schematic of the preamplifier system.

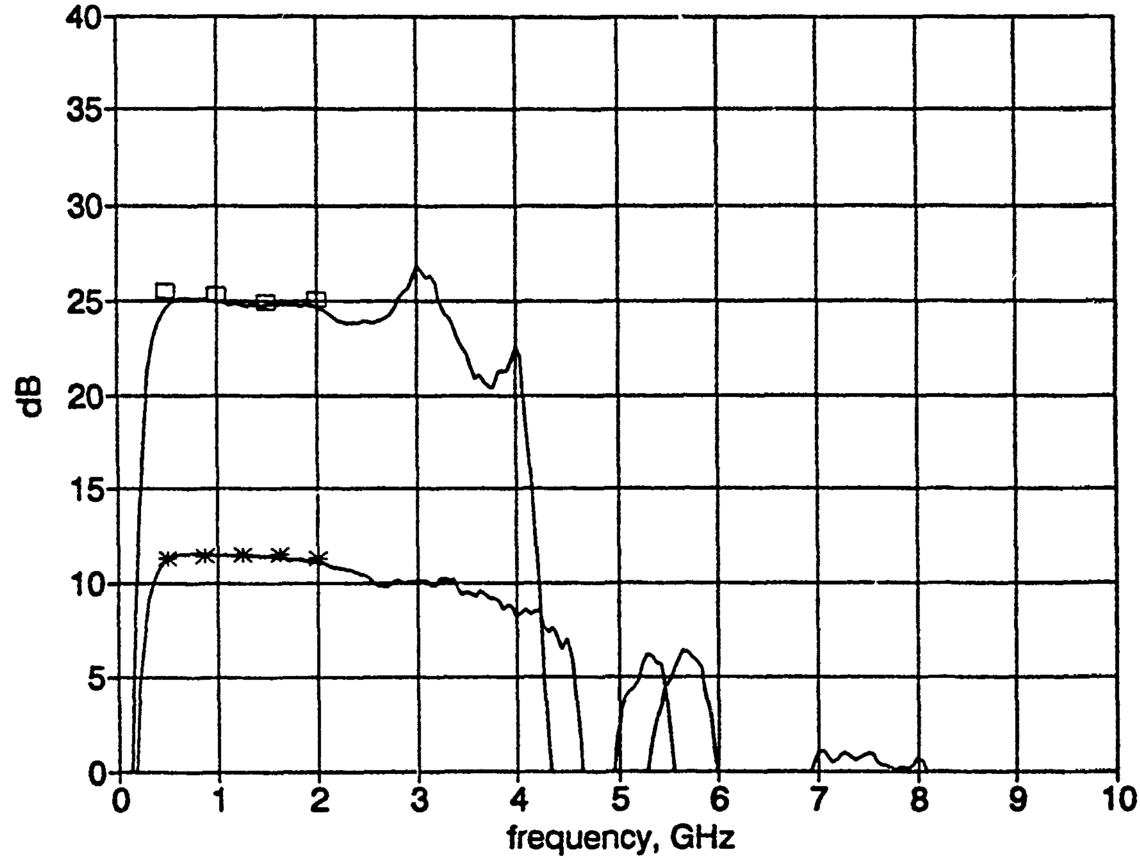


Figure 4. Gains of the 0.5- to 2-GHz preamplifiers; Vendor (symbol) and Aerospace (line) measured data.

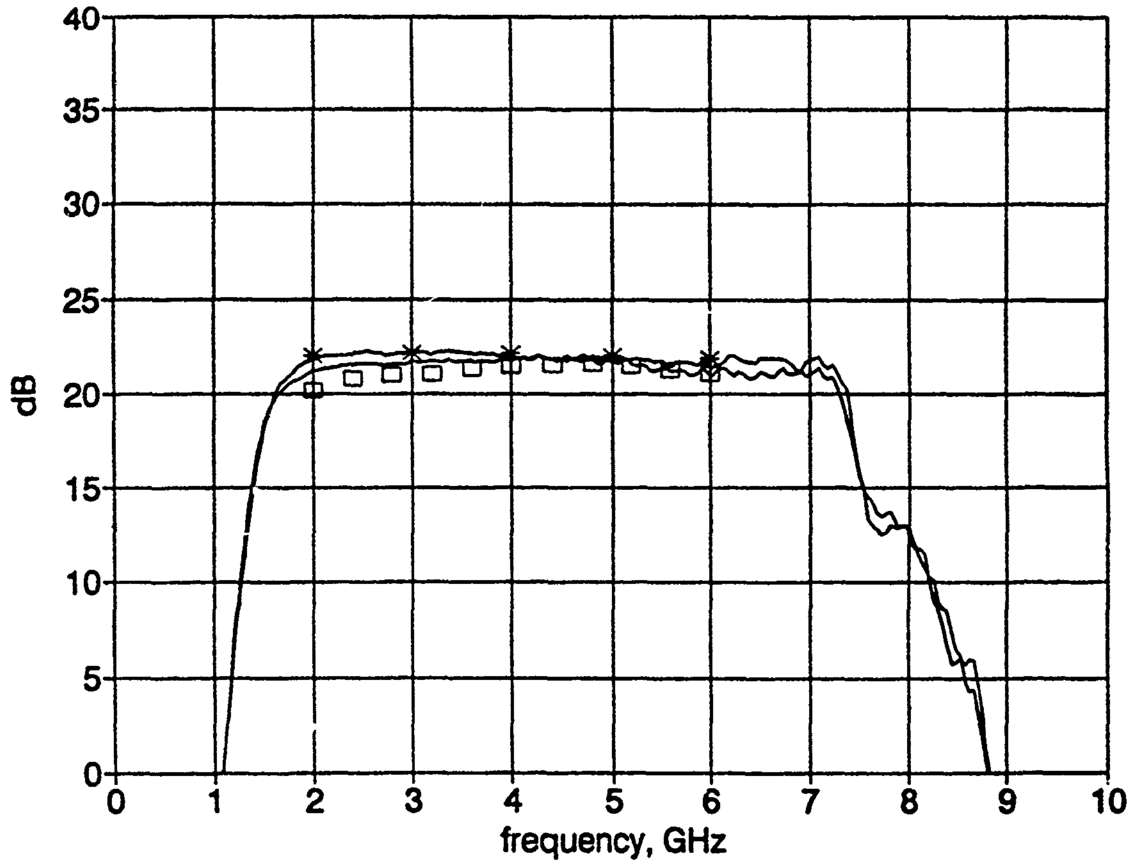


Figure 5. Gains of the 2- to 6-GHz preamplifiers; vendor (symbol) and Aerospace (line) measured data.

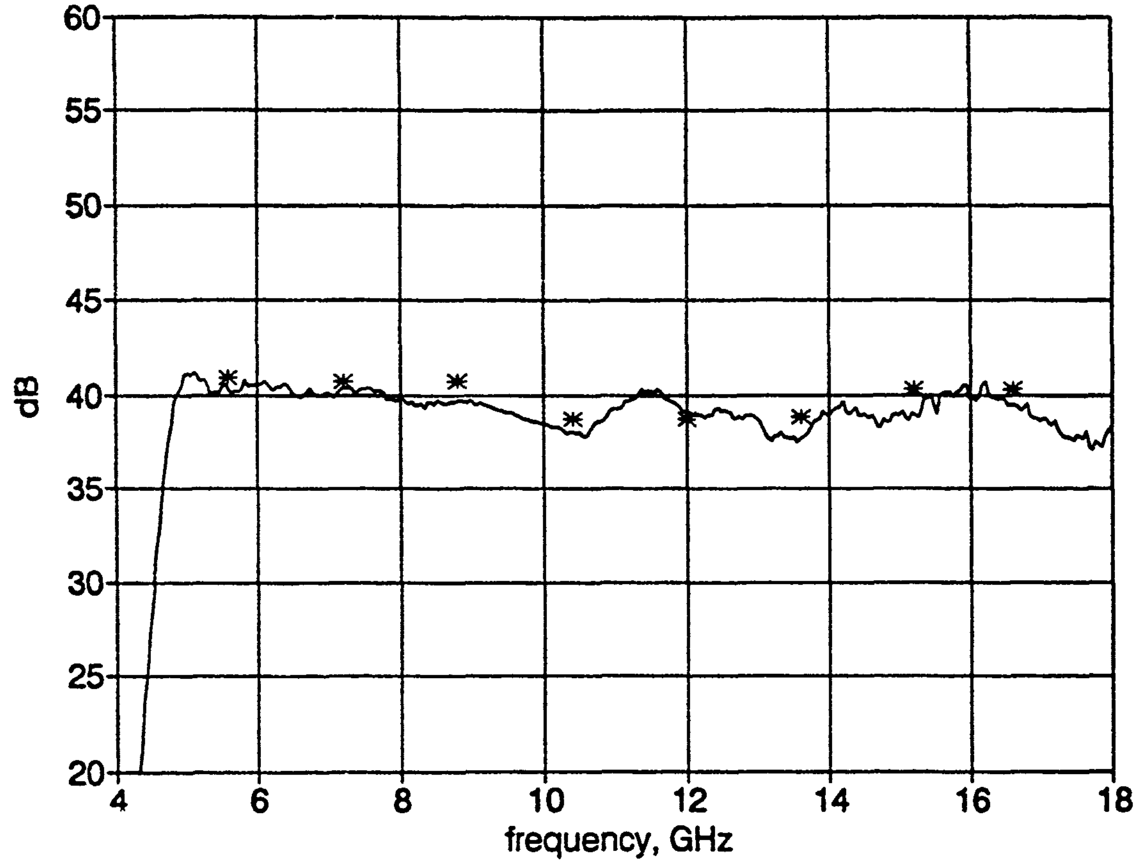


Figure 6. Gain of the 6- to 18-GHz preamplifier; vendor (symbol) and Aerospace (line) measured data.

Table 1. Noise Figures of the Preamplifiers in dB.

Preamplifier	Noise Figure (Aerospace)	Noise Figure (Vendor)
.5-2	2.6	2.3
2-6	3.3	3.2
6-18	3.7	3.1

Table 2. 1-dB Compression Points of the Preamplifiers.

Preamplifier	Compression Point (dBm)
.5-2	13
2-6	15
6-18	18

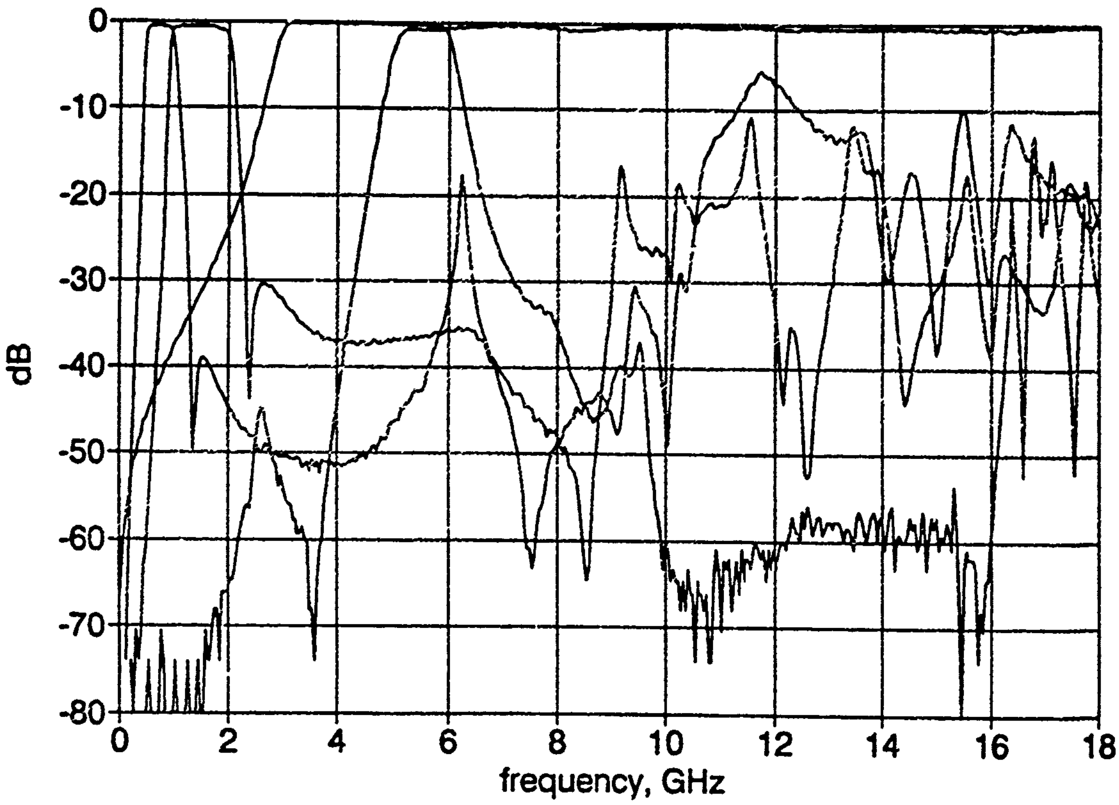


Figure 7. Filter band-pass characteristics.

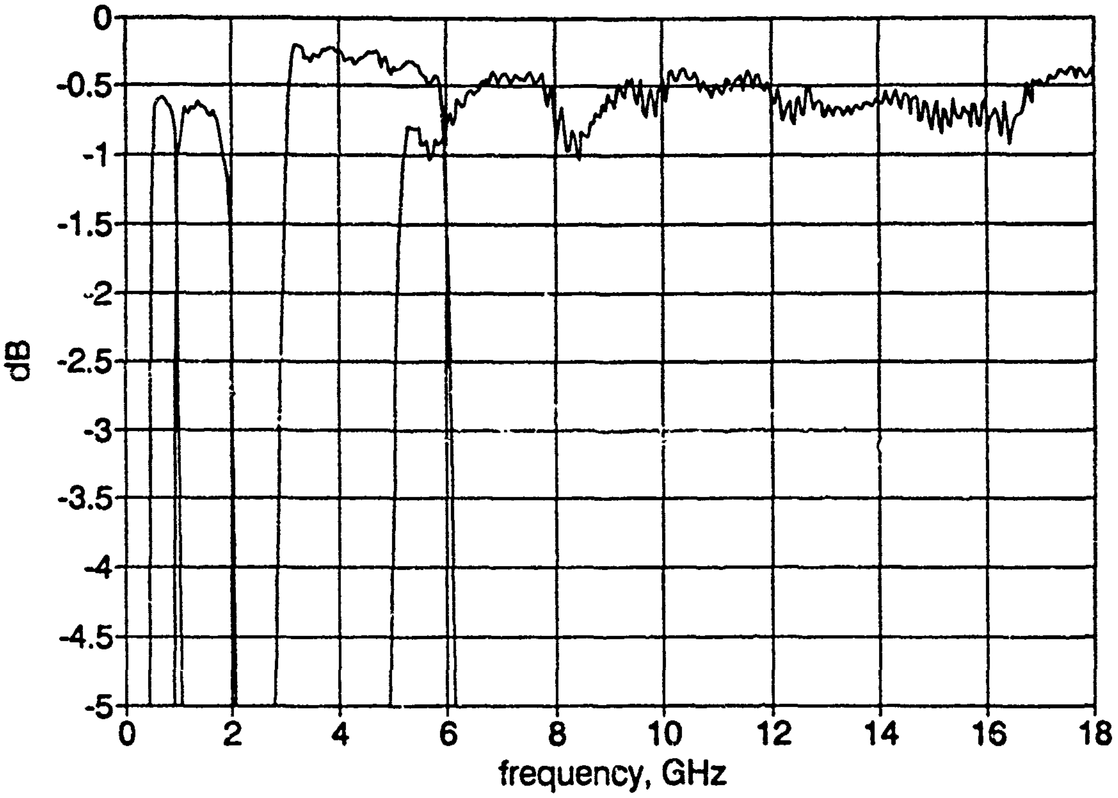


Figure 8. Filter insertion losses.

signal within their operating range. Their band rejection performance at a typical frequency and their insertion loss characteristics are shown in Figures 9 and 10 respectively. The band-reject frequencies for YIG filters depend on the dc voltage biasing the YIG sphere. This voltage is controlled through thumbwheel settings; a detailed tabulation of the dc voltage versus band-reject frequency is found in Table 3.

The preamplifier system is shown in Figure 11. The amplifiers are located in the upper portion of the unit; the YIG filters and controller are located in the lower portion of the unit. The four passive filters are manually inserted in front of the unit, as indicated in Figure 3.

The overall sensitivity of the system is specified by its G/T, shown in Figure 12. This data uses the antenna gain values (Figure 13), the cable losses between the antenna and the preamplifier (Figure 14), and a variety of filtering and preamplification combinations that are representative of operating conditions encountered during measurements. The benefits of preamplification and the gain of the log periodic antenna are clearly seen. For reference purposes, the G/T of a system having an isotropic gain level and a 200-deg-K system is also shown in this figure. This G/T value represents a high-performance ground terminal in the sidelobe region, and differs from the peak G/T of the terminal, which includes the main-beam antenna gain. Clearly, the filtering must be used to maximum benefit in maintaining the overall system sensitivity.

The dynamic range of the measurement also varies with the preamplifier used during the measurements. The 1-dB compression point of the spectrum analyzer is -5 dBm, and the compression points of the individual preamplifiers are listed in Table 1. The resulting levels seen on the spectrum analyzer and at the system input are shown in Figure 15.

Finally, the readings on the spectrum analyzer must be related to the power levels of the incident fields. Since one is interested in the power level at the input to the ground terminal receiver, a conversion factor for deriving that level from the spectrum analyzer reading is beneficial. The conversion factor combines the gains of the log periodic antenna and the preamplifiers with the losses of the cable and the filters. The conversion between the spectrum analyzer readings and the power levels that would be received by an isotropic antenna is presented in Figure 16 for a variety of preamplifier and filtering combinations.

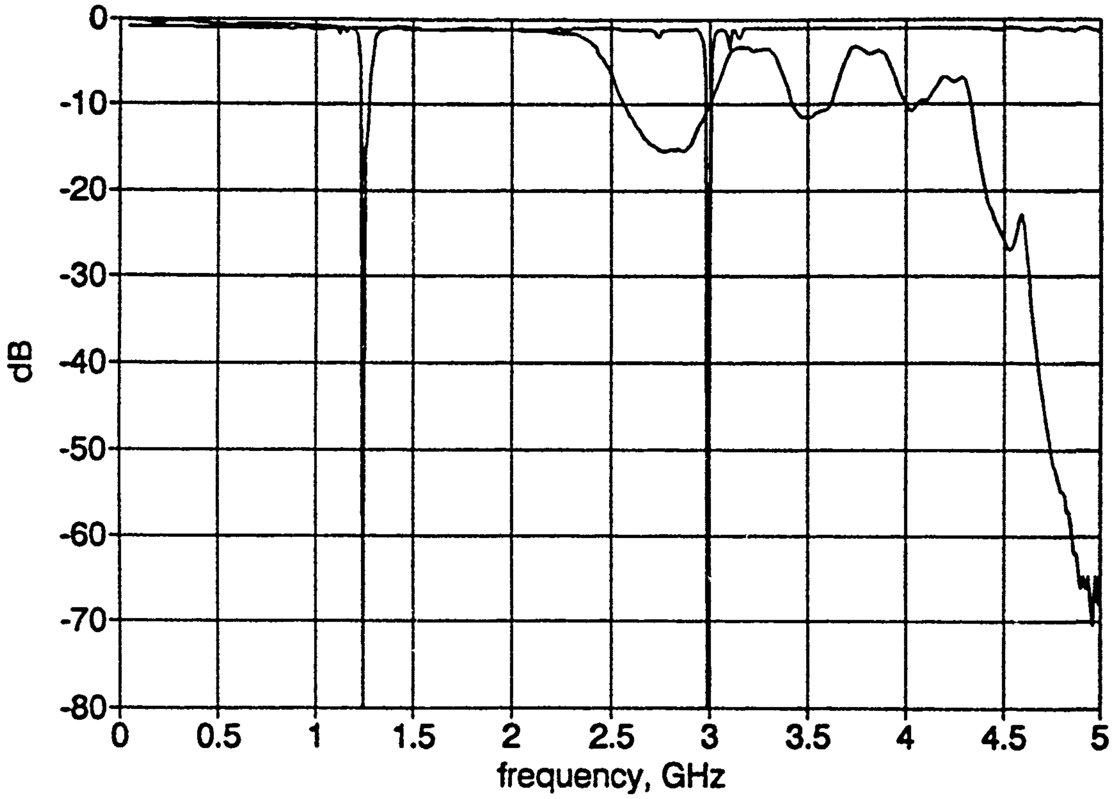


Figure 9. YIG filter band-rejection performance.

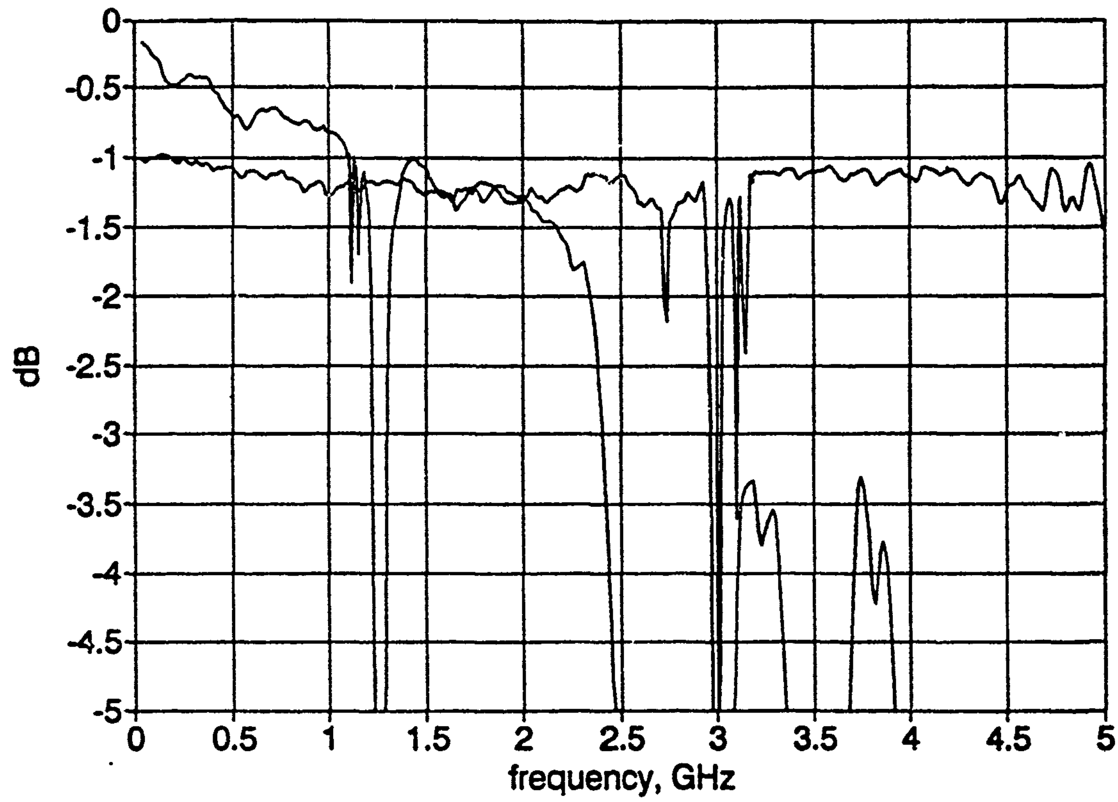


Figure 10. YIG filter insertion losses.

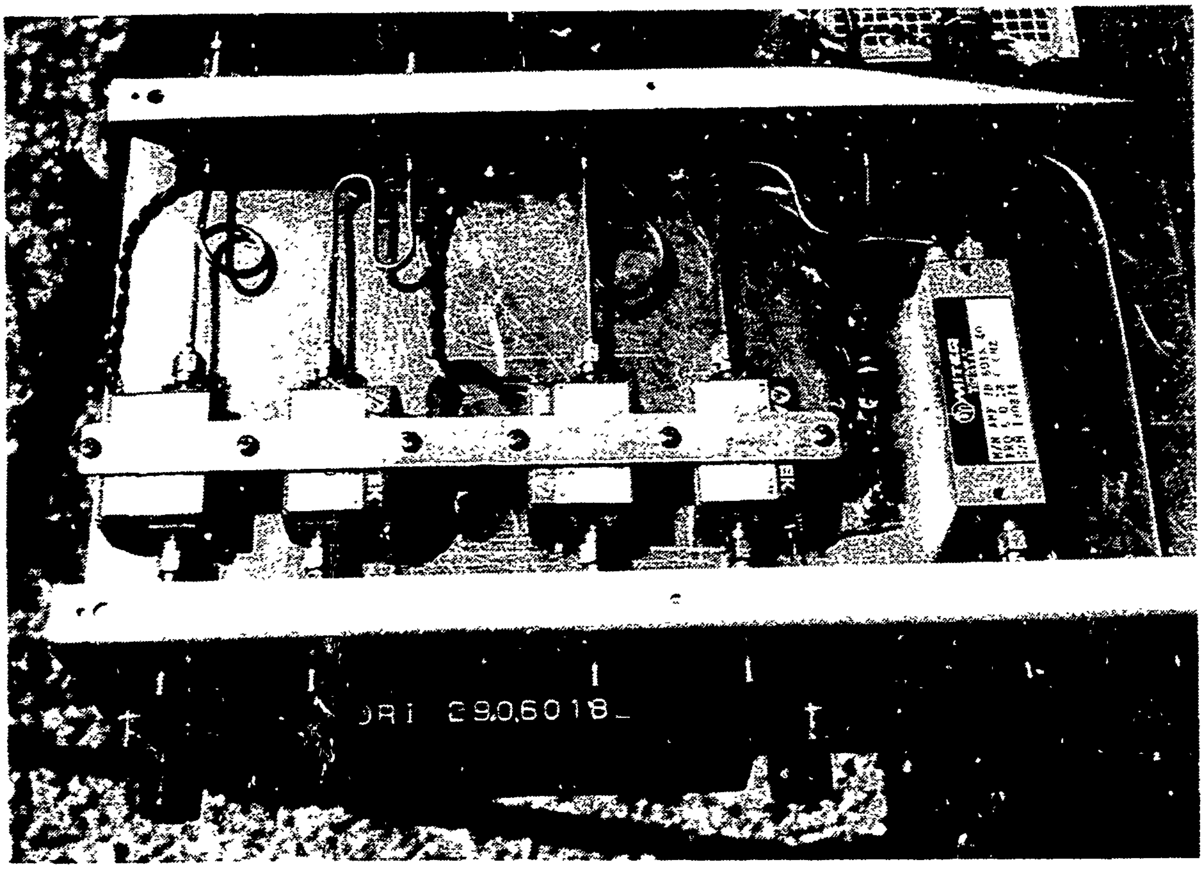


Figure 11. Preamplifier system

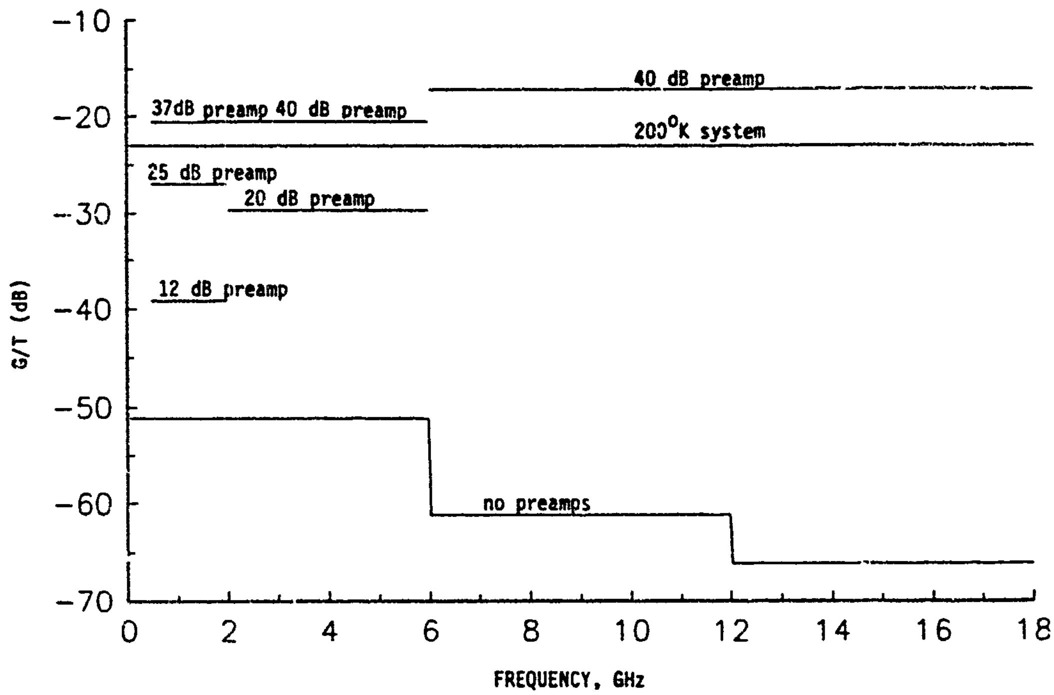


Figure 12. G/T of the measurement system.

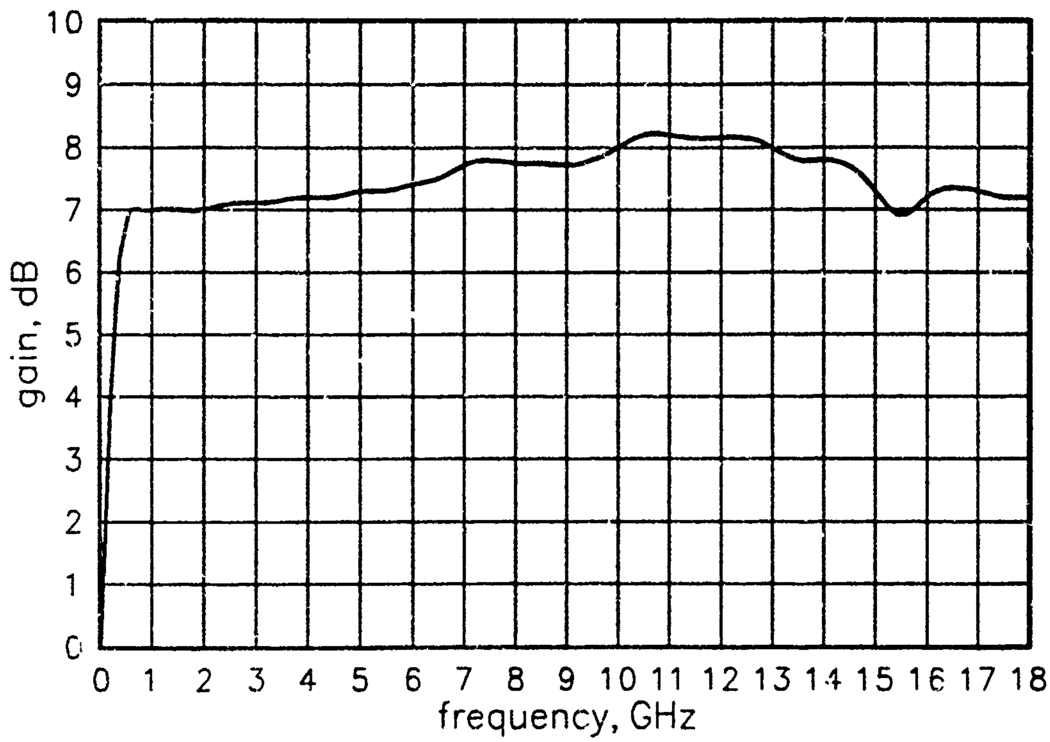


Figure 13. Antenna gain

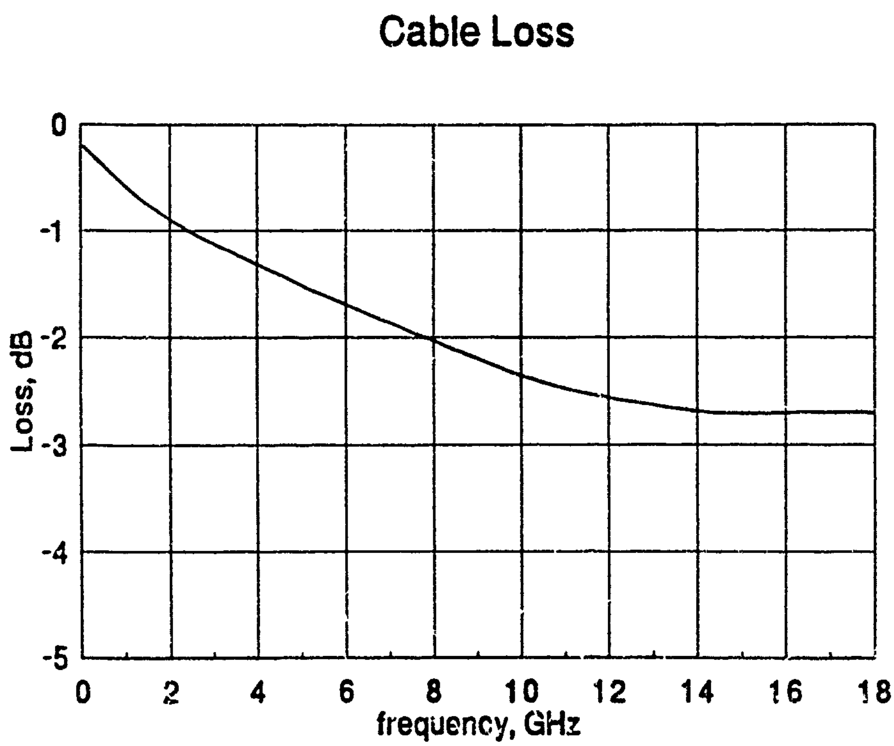


Figure 14. Cable insertion losses.

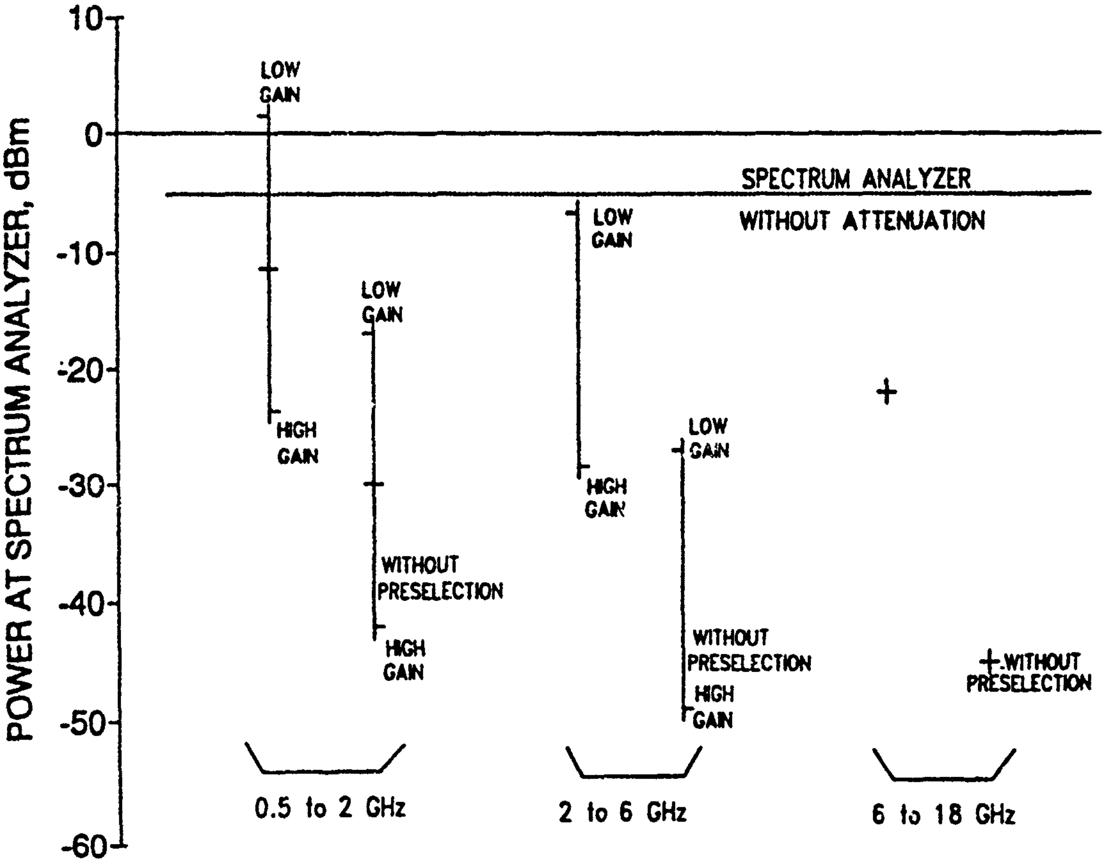


Figure 15. System input levels that cause the preamplifiers to saturate, and the indicated spectrum analyzer levels.

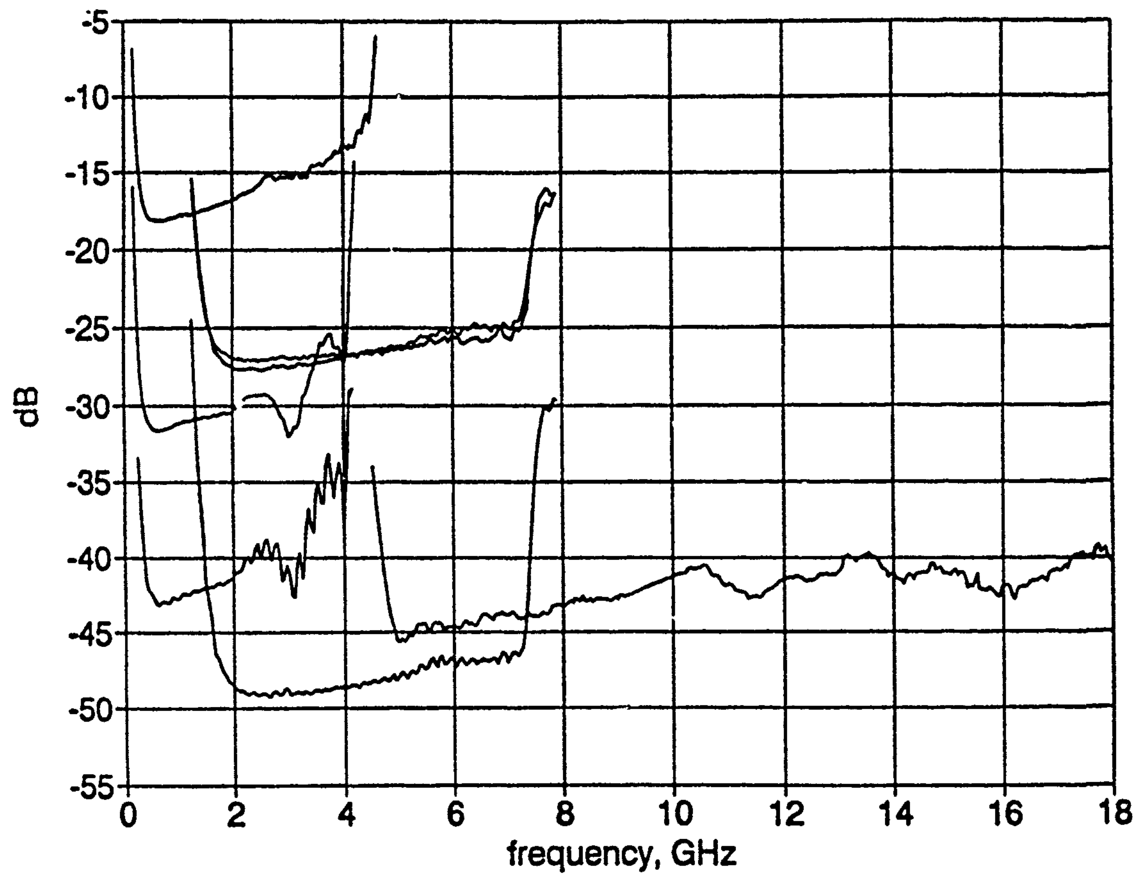


Figure 16. Conversion factor for relating spectrum analyzer power levels to power levels that would be received with an isotropic antenna.

Table 3. Tuning Voltages of the YIG Filters

Tuning Voltage, Volts	Linear Frequency, GHz
0	.500
1	.650
2	.800
3	.950
4	1.100
5	1.250
6	1.400
7	1.550
8	1.700
9	1.850
10	2.000

(a) 500-MHz to 2-GHz YIG Band-Reject Filter

Tuning Voltage, Volts	Linear Frequency, GHz
0	2.000
1	2.200
2	2.400
3	2.600
4	2.800
5	3.000
6	3.200
7	3.400
8	3.600
9	3.800
10	4.000

(b) 2-GHz to 4-GHz YIG Band-Reject Filter

III. SYSTEM OPERATION

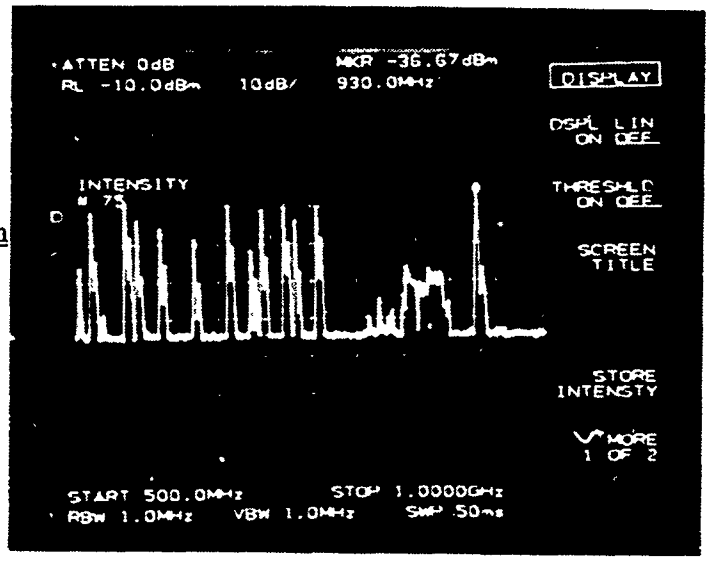
RFI surveys at remote sites proceed in basically two steps. The first step is a frequency sweep through the entire bandwidth without the use of any preamplification. The purpose of the sweep is to identify high-level signals that are capable of saturating the measurement system, and to determine the combination of preamplifiers and filters that can be used while maintaining linear system operation. The second step is to repeat these measurements with the appropriate preamplification and filtering to search for lower-level signals that can be detected with the highest achievable sensitivity. Detailed spectra for the individual signals are recorded during the second step. Both steps are performed using multiple antenna directions and polarizations to identify the maximum power levels. The antenna azimuth position is referenced to true north. The measurements are repeated over a period of time, typically a week, to observe the maximum power levels, operating schedules, consistency of results, etc.

A very simple site measurement was performed on the roof of Building A2 to illustrate this measurement procedure and provide examples of data measured by this system. These measurements were performed over a two-hour period, so that consistency of power levels, operating schedule, etc. that are possible for longer operating periods were not observed. Building A2 is a two-story structure located about 1.5 miles south of the Los Angeles International Airport. As anticipated, the measured spectrum will show a significant amount of television signal and other spectra associated with a typical urban environment, but also a significant amount of microwave activity from the airport avionics.

The first part of the survey was a measurement of the 500-MHz to 18-GHz frequency range. These measurements are shown in Figure 17 and are presented in 500-MHz to 1-GHz, 1- to 2-GHz, 2- to 2.9-GHz, 2.75- to 6-GHz, and 6- to 18-GHz frequency spans. Television signals and other UHF emitters are prominent at the lower frequencies, and radar signals are present at L-, S-, C-, and X-band frequencies that are associated with the airport systems. Detailed spectra of the television signals, radio-telephone activity, and the L- and S-band radars shown in Figure 18 display the spectral characteristics of some of the more prominent signals more clearly.

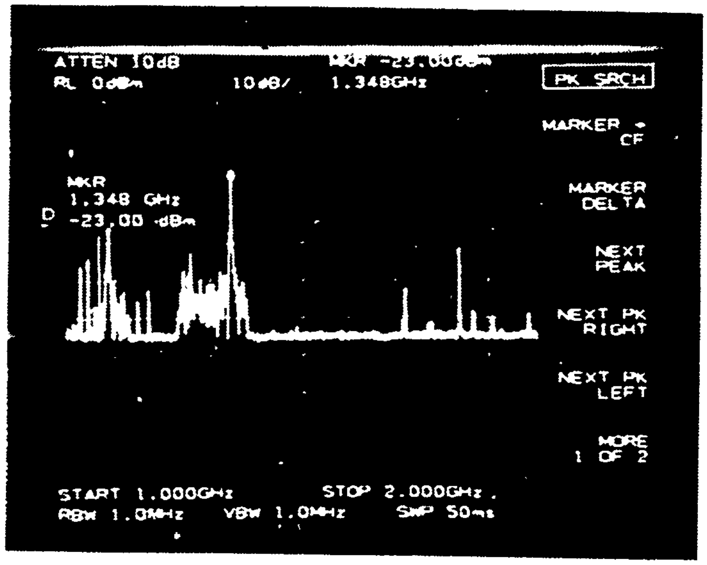
The gain characteristics of the system shown in Figure 16 are used to establish power levels on the individual spectra. An isotropic gain value is used as a reference level for this calibration level as previously discussed. The power level is referenced to a -60-dBm level. This level is not only convenient for these spectral displays but is also a typical 1-dB compression level for microwave receivers. Thus, the measured results indicated that, without filtering, the local television signals, some of the communication signals, and the radar systems would saturate microwave systems operating at this location.

-60dBm
@0dBi



(a) 500 to 1000 MHz

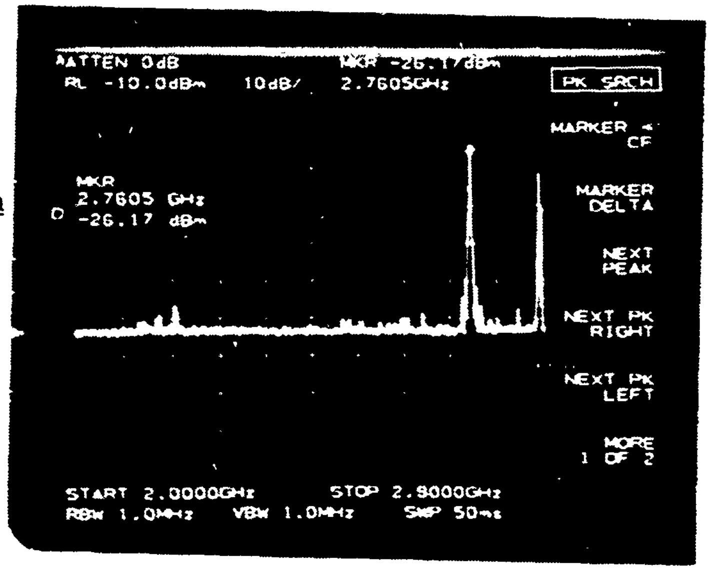
-60dBm
@0dBi



(b) 1 to 2 GHz

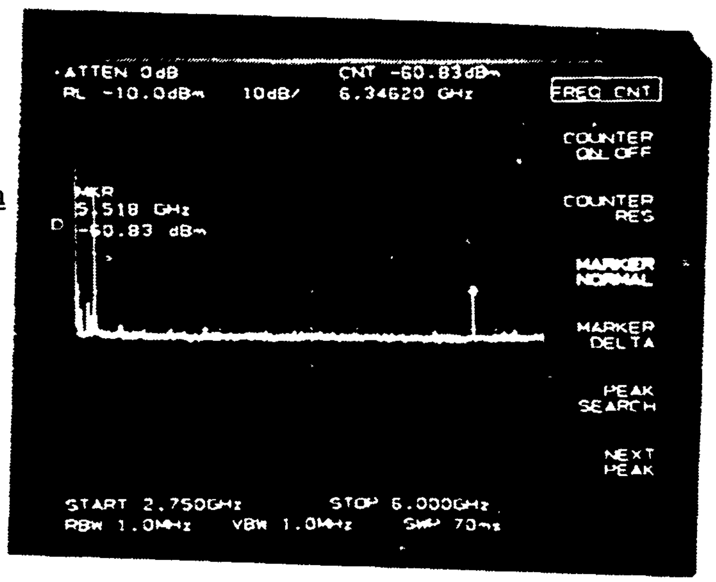
Figure 17. Frequency sweeps.

-60dBm
@0dBi



(c) 2 to 2.9 GHz

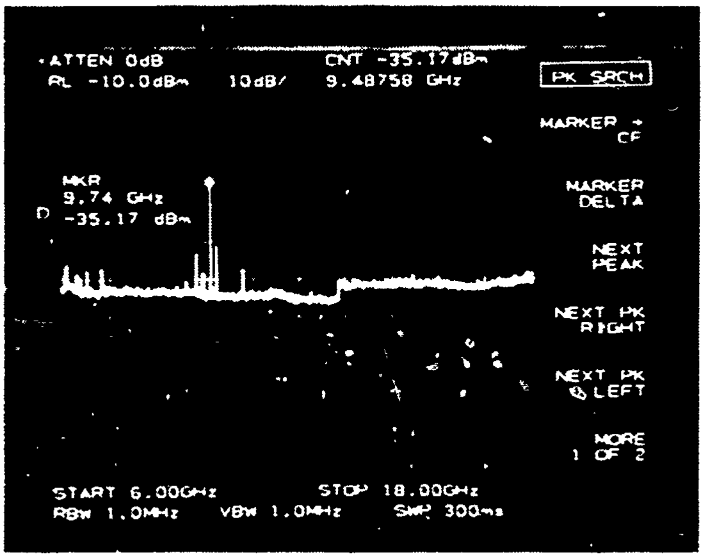
-60dBm
@0dBi



(d) 2.75 to 6 GHz

Figure 17. Frequency sweeps (continued)

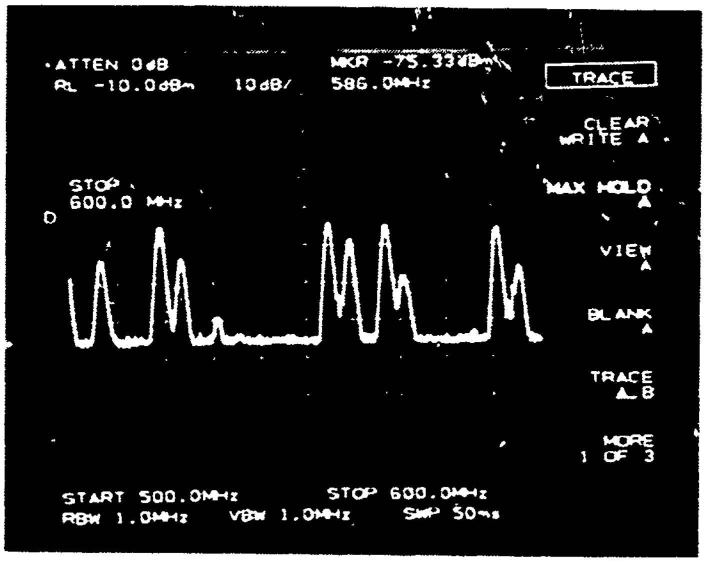
-60dBm
@0dBi



(e) 6 to 18 GHz

Figure 17. Frequency sweeps (continued)

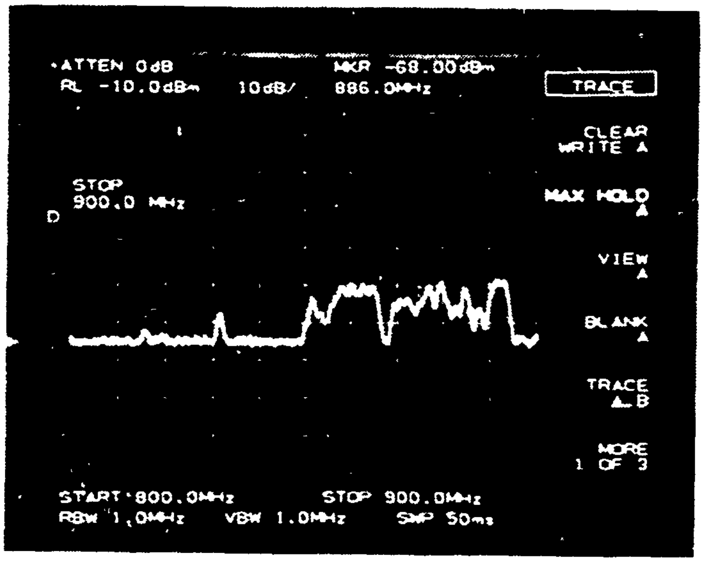
-60dBm
@0dBi



(a) Television spectra

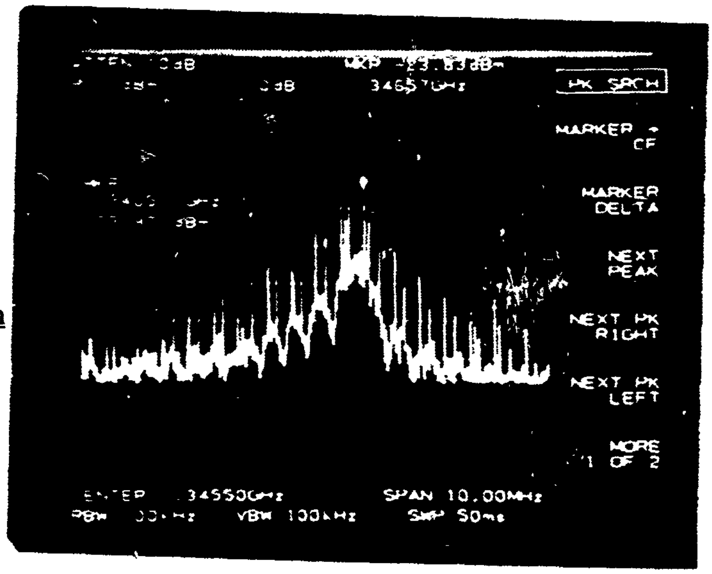
Figure 18. Signal spectra

-60dBm
@0dBi



(b) Radio Telephone Spectrum

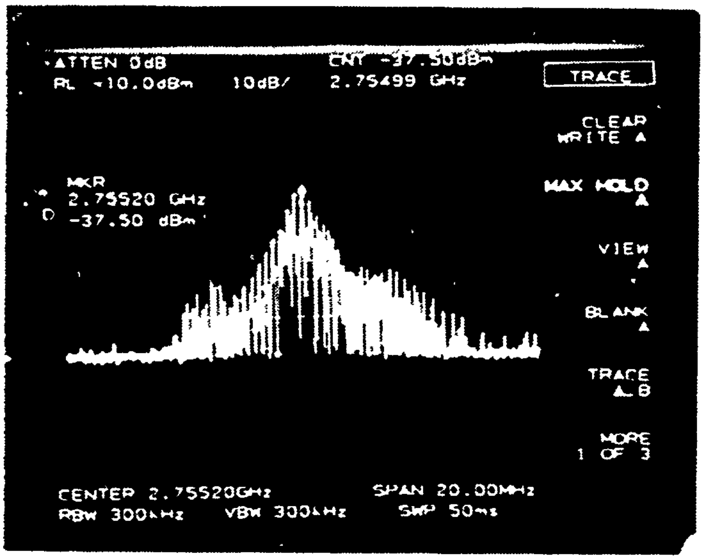
-60dBm
@0dBi



(c) L-band Radar Spectrum

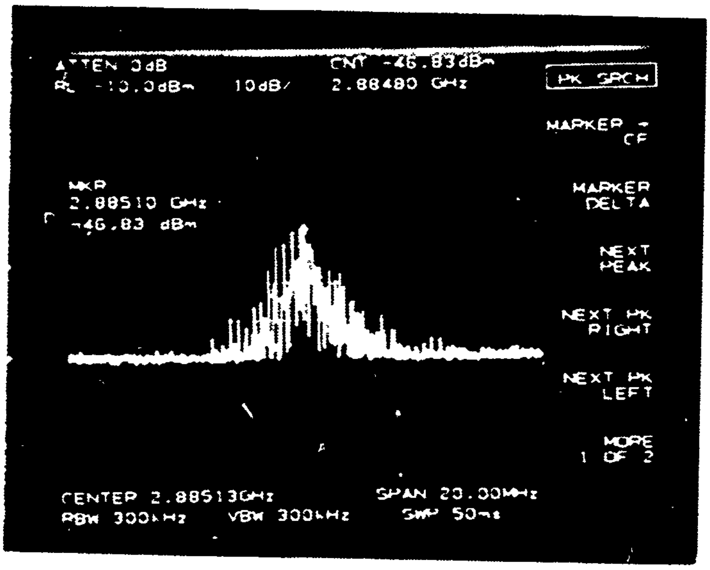
Figure 18. Signal spectra (continued)

-60dBm
@0dBi



(d) S-band Radar Spectrum

-60dBm
@0dBi



(e) S-band radar spectrum

Figure 18. Signal spectra (continued)

IV. SUMMARY

A system has been developed to measure the RF environment at remote sites where ground terminals are located. This system establishes the power levels and spectral characteristics of local interference signals that can limit the operation of the terminal. The key features of the measurement system are:

1. It is sufficiently simple, compact, and rugged to permit air shipment to remote sites.
2. Frequency coverage of 0.5 to 18 GHz encompasses most of the signals that would be of concern to a microwave terminal.
3. The sensitivity of the system meets or exceeds that of a typical ground terminal in its sidelobe region where ground-based interference is assumed to arise.
4. A combination of filtering, gain distribution, and attenuation provide versatility in maintaining system linearity in a variety of high-power RF environments.

V. REFERENCES

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